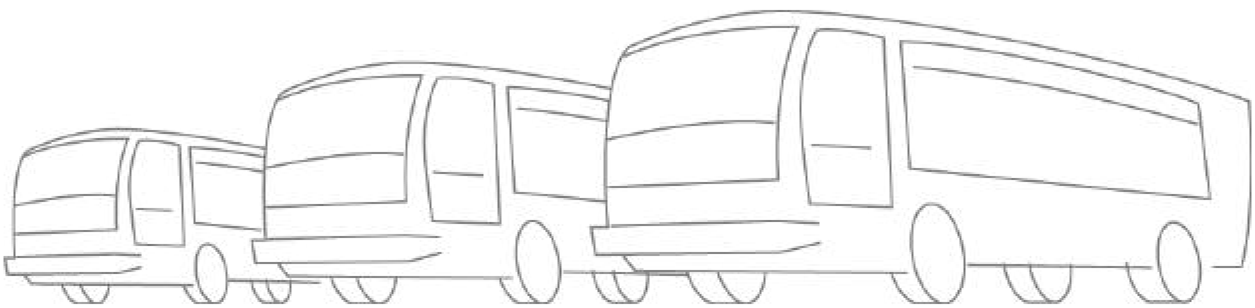
THE PUBLIC TRANSIT BUS FLEET RULE STATUS REPORT



California Air Resources Board Public Meeting
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EXECUTIVE SUMMARY

Since its inception, the Air Resources Board (Board or ARB) has worked towards protecting the health of Californians from air pollution. In August 1998, the ARB identified particulate matter (PM) from diesel-fueled engines as a toxic air contaminant and began working on a plan to reduce the risk from diesel PM emissions. On average, current urban diesel buses emit more emissions of oxides of nitrogen (NOx) and PM than if all bus riders were driving separately. Significant improvements in heavy-duty vehicle technology, however, can result in clean public transportation and help reduce the public's exposure to harmful PM emissions. By taking advantage of engine improvements and new aftertreatment technologies, transit agencies and the ARB can be partners in achieving new air quality benefits from public transportation.

In February 2000, the ARB adopted the public transit bus fleet regulation. This regulation is designed to achieve significant reductions in PM and NOx emissions from 2001-2015, through the implementation of a fleet rule. Emission reductions are achieved through purchasing new low-emission buses or repowering older, higher-emitting buses to lower-emitting configurations. Reductions in diesel PM are also achieved through the retrofit of engines with emission control systems and the use of low sulfur fuel. Long-term emission reductions are achieved through establishing increasingly more stringent new engine standards. Over time, ultra-low, near-zero, and zero emissions buses will replace older higher emitting engines.

The Board, through discussion at the February 24, 2000, public hearing and Resolution 00-2 (February 24, 2000), directed staff to provide regular updates on the progress of implementation of the regulation. Specifically, directives to staff were (1) to report back regularly on transit agency progress in implementing the regulations; (2) to report back to the Board on implementation of emission reduction strategies as an alternative to compliance with the 2004 standards and to analyze the first exemption application and present its recommendation before the Board as part of the first update (3), to report on the status of advanced aftertreatment systems; and (4) to report on progress on the development of hybrid-electric bus test procedures.

Each transit agency to which the rule applied was required to select a fuel path and submit its selection by January 31, 2001. Seventy transit agencies are subject to the regulation. Of these transit agencies, 61 percent chose to follow the diesel path while 39 percent chose to follow the alternative-fuel path. As of January 31, 2001, transit agencies reported that they operate 6679 diesel buses and 1866 alternative-fuel buses. By October 1, 2002, transit agencies report they will operate 6158 diesel buses, a decrease of 8 percent, and 2754 alternative-fuel buses, an increase of 48 percent.

Transit agencies were required to submit their NOx fleet averages, based on engine certification values, as of January 1, 2001. If the NOx fleet average was higher than 4.8 grams per brake horsepower-hour (g/bhp-hr), transit agencies were required to submit a report detailing actions planned to achieve that average by October 1, 2002. As of August 1, 2001, 68 of the 70 transit agencies subject to this rule had submitted both the 2001 and 2002 NOx fleet averages. Eighty-two percent of the transit agencies either presently comply with the 4.8 g/bhp-hr NOx fleet average or will by October 1, 2002.

Transit agencies will be retiring, repowering or purchasing alternative fuel buses to lower their fleet emission averages. Eleven transit agencies submitted data that, according to staff's analysis, indicates they will continue to exceed the 4.8 g/bhp-hr fleet average. Staff has contacted these transit agencies and will work with them to move them into compliance.

The engine standards in title 13, California Code of Regulations (CCR), section 1956.1 and provisions of title 13, CCR, sections 1956.2(d)(4) and 1956.2(c)(5) prohibit transit agencies from purchasing transit bus engines during model years 2004 through 2006 that exceed a NOx emission standard of 0.5 g/bhp-hr. The regulation includes an alternative strategy that the transit agencies can follow if bus engines meeting this standard are not available, as engine manufacturers have indicated is possible. The strategy allows transit agencies the option to apply for an exemption by June 30, 2001, from purchasing engines that meet the 2004-2006 model year (MY) engine emission standards, by demonstrating to the ARB Executive Officer that they can achieve greater emission reductions by other means through the year 2015. Transit agencies must also demonstrate advanced NOx aftertreatment technology [title 13, CCR, sections 1956.2(c)(8) and (d)(7)]. Transit agencies that are approved for the exemption may purchase 2004-2006 MY diesel engines with certified NOx emissions higher than 0.5g/bhp-hr NOx. The exemption is the only mechanism allowed by the law for transit agencies to purchase non-complying diesel engines during those three years. Alternatively, there is no requirement that transit agencies must purchase buses during 2004-2006, so compliance could be achieved by not purchasing any diesel buses .

As of the June 30, 2001, deadline, 15 transit agencies had submitted requests for an exemption. Of the 15, Alameda/Contra Costa Transit, Golden Gate Bridge Highway and Transportation District (Golden Gate Transit), Santa Clara Valley Transportation Authority (VTA), and Montebello Bus Lines submitted one or more plans to demonstrate greater NOx reductions through 2015. As of the August 15, 2001, status report deadline, VTA was the only transit agency that submitted a complete plan that demonstrates greater NOx emission benefits through 2015, as required. Staff's analysis of the plan shows that the plan fulfills the requirement of the regulation, and thus, the plan provides a good framework that can be followed by other transit agencies. Three of the four transit agencies mentioned above submitted incomplete plans. Twelve transit agencies submitted only an application for exemption requesting additional time and assistance in preparing plans. In addition, between June 30 and August 15, 2001, staff has received one letter and several verbal requests by transit agencies that would like to submit late exemption applications.

None of the transit agencies that applied for exemptions as of June 30, 2001, indicated that they were demonstrating or had contracted to demonstrate advanced NOx aftertreatment technology. This is an important requirement of the exemption regulation and is necessary to help ensure viability of the technology for meeting the 2007 engine exhaust standards. Staff has concluded that transit agencies need additional time to initiate the required demonstration programs.

Staff has provided an update on the status of NOx aftertreatment technology in this report. Controlling NOx emissions from diesel engines is inherently difficult because the oxygen-rich exhaust environment makes reduction, i.e., the removal of an oxygen molecule, difficult to achieve. NOx absorbers have shown greater than 80 percent reduction potential in development programs, and are considered one of the most promising technologies for NOx reduction. Selective catalytic reduction has been in use in stationary sources for many years, but to date its application in mobile sources is limited and still under development. Manufacturers are focusing research and development efforts on achieving significant (i.e., 90 percent) emission reductions in the 2007 to 2010 time frame. However, the national NOx standards which were slated for implementation in 2007, when the transit bus regulation was adopted, have now been finalized for 2010. This change translates into a delay of early demonstration programs, so NOx emission controls are not yet available to transit agencies.

The regulation also require transit agencies to reduce particulate matter emissions by retrofitting their bus engines with advanced aftertreatment technology that reduces particulate matter exhaust emissions by a minimum of 85 percent. Staff has established a program to verify these aftertreatment devices, and as of August 2, 2001, two devices for some later model engines have been verified. Currently there are no retrofit devices verified for engines older than 1995 MY and no devices are verified for any two-stroke engines. The transit bus rule requires transit agencies to retrofit 100 percent of their pre-1991 MY diesel engines, and differing percentages of their 1991 to 1995 MY diesel engines, depending on their fuel path, by January 1, 2003. The regulation provides for a one year delay in the event that retrofit devices are not available within six months of the required implementation date. Staff, therefore, will update the Board by July 2002 on the availability of particulate matter retrofit devices for older engines.

The Board also instructed the staff to develop a test procedure for the evaluation of hybrid-electric bus emissions. This issue requires more time to resolve. The ARB is actively participating in a government-industry working group and is testing hybrid-electric bus emissions to develop a test procedure and certification standards. Staff anticipates presenting to the Board a test procedure for certification of diesel hybrid-electric bus systems in late 2002.

In conclusion, staff has analyzed the implementation issues and exemption applications for the alternative NOx reduction strategy. Based on these analyses and the delay in the full compliance date for the national NOx standards, staff makes the following recommendations to the Board:

- Staff recommends that the Board direct the Executive Officer to allow transit agencies that applied for an exemption and submitted a plan demonstrating greater NOx benefits through 2015 additional time to demonstrate advanced NOx aftertreatment technology. The schedule staff recommends is as follows: transit agencies must commit resources to a demonstration project as of March 31, 2002, and advanced NOx aftertreatment demonstrations must be in progress as of March 31, 2003.

- Staff further recommends the Board allow each transit agency the option of performing the demonstration individually or jointly. If the transit agencies elect a joint project, then the demonstration must include at least three buses and demonstrate NOx aftertreatment technology that will offer commercial potential (i.e., lower NOx emissions by 70-90 percent). Transit agencies that elect individual demonstrations shall include at least one bus.

If the Board approves these recommendations, the Executive Officer will continue to work with the transit agencies to implement them and will report on the progress.

I. BACKGROUND

A. California's Air Quality

Over the past three decades, California has made dramatic progress towards achieving the goal of cleaner air. The progress is largely a result of California's leadership in developing unique pollution control programs to reduce emissions from both vehicular and non-vehicular sources. The California Air Resources Board (ARB or Board) is the state agency responsible for achieving state and federal clean air goals. Stringent regulatory programs have reduced peak ozone concentrations in southern California today to about one-third of the values in the 1960s, despite significant increases in population and the number of motor vehicles. In addition, the number of days exceeding both the federal and state one-hour ambient ozone standards has steadily declined. Since 1980, the number of days exceeding the federal and state standards has decreased statewide by about 60 percent and 50 percent, respectively.

B. Need for Control

Despite significant improvements in California's air quality over the last thirty years, however, there is still more work to do to achieve air quality goals set forth in federal and state statutes. California currently has eight major areas that are in nonattainment with the one-hour federal ambient ozone standard. These areas include the South Coast Air Basin, the Sacramento Metropolitan area, San Diego Air Basin, San Joaquin Valley Air Basin, Southeast Desert Air Basin, the San Francisco Bay Area, Santa Barbara County, and Ventura County. In addition, four air districts (or a portion of an air district) are currently classified as federal nonattainment areas for particulate matter (PM or PM_{10}). These air districts include the San Joaquin Valley Air Pollution Control District, South Coast Air Quality Management District, a portion of the Great Basin Unified Air Pollution Control District, and a portion of Imperial Valley Air Pollution Control District. All but one air district, Lake County Air Quality Management District, is in non-attainment for the more stringent California PM_{10} air quality standards.

1. Oxides of Nitrogen

Oxides of nitrogen (NOx) emissions are produced almost entirely by combustion processes. During combustion, oxygen reacts with nitrogen to form nitric oxide (NO), nitrogen dioxide (NO_2), and relatively small amounts of other compounds of oxygen and nitrogen. NOx reacts with hydrocarbons (HC), in the presence of sunlight, to form ozone. Ozone is the major constituent of what is commonly referred to as smog. There are a variety of harmful health effects associated with ozone. Ozone impairs lung function by irritating and damaging the respiratory system. In addition, ozone causes damage to vegetation, buildings, rubber, and some plastics (ARB 2001a).

In addition to its role in ozone formation, NOx emissions also damage respiratory systems and lower resistance to respiratory infection (ARB 1999b). Furthermore, photochemical reactions in the atmosphere convert oxides of nitrogen into nitrate salts and compounds, which in many areas of California contribute substantially to fine PM pollution (ARB 1997). Health effects of PM are described in section two below.

The major sources of NOx emissions in California are on-road motor vehicles, off-road mobile sources (e.g., construction and farm equipment, trains, and aircraft), and stationary combustion sources (e.g., oil and gas production and refining, manufacturing and industrial, electric utilities). It is estimated that on-road mobile sources account for about 52 percent of the 2000 statewide NOx inventory (ARB 2001a).

ARB has set stringent engine emission standards to curb NOx emissions. The current NOx standard for on-road heavy-duty vehicles, including urban buses, is 4.0 grams per brake horsepower-hour (g/bhp-hr), as compared to an uncontrolled level of 10-12 g/bhp-hr. This standard will further decrease to 0.5 g/bhp-hr for 2004-2006 model year (MY) diesel and dual-fuel urban bus engines and 0.2 g/bh-hr for all MY 2007 and beyond diesel engines. Many engine manufacturers believe NOx aftertreatment technology will be necessary to comply with these more stringent standards.

2. Particulate Matter

Particulate matter is generated, most commonly, in combustion processes (e.g., trucks and cars), agricultural activities, and livestock operations (ARB 2000d). Particulate matter, like ozone, has been linked to a range of serious health problems. Very small particles, 2.5 µm in diameter or smaller, are deposited deep in the lungs. The effects of PM emissions exposure include increased respiratory symptoms and disease; decreased lung function, particularly in children and individuals with asthma; alterations in lung tissue and respiratory tract defense mechanisms; and premature death. Increased hospital admissions and emergency room visits are common following elevated PM concentrations in the air. California currently has a PM_{10} standard of 50 micrograms per cubic meter ($\mu g/m^3$) for a 24-hour period and no separate $PM_{2.5}$ standard (ARB 1999a).

In August 1998, the ARB identified PM emissions from diesel-fueled engines as a toxic air contaminant in accordance with the Health and Safety Code, section 39660. Data from air monitoring and modeling indicate that the PM emissions from diesel-fueled engines are by far the most significant toxic risk faced by the citizens of California. An estimated 70 percent of the total carcinogenic risk from all air toxics results from diesel PM emissions. Diesel buses, operating in heavily congested urban areas, directly emit toxic diesel particulates at ground level and impact pedestrians, vehicle drivers, and passengers.

C. Regulatory Focus

The ARB reduces air pollution through adopting and enforcing various regulations and control measures. Mobile source emissions account for about 60 percent of ozone precursors such as NOx and HC and about 40 percent of combustion PM emissions statewide. Controlling these emissions, therefore, plays a vital role in attaining ARB's air quality goals. Mobile source diesel engine emissions account for about 30 percent of the total combustion PM emissions. Following the identification of diesel PM as a toxic air contaminant in 1998, the ARB was mandated to develop a control plan to reduce risks (Health and Safety Code, section 39658). In September 2000, the Board approved a plan to reduce risks statewide from diesel PM, which includes several measures to reduce diesel PM emissions from both mobile and stationary sources (ARB 2000c).

The public transit bus fleet regulation adopted in February 2000 is one measure designed to control NOx and PM from diesel engines. Significant improvements in bus engine technology can result in clean public transportation and help reduce public exposure to harmful emissions. By taking advantage of these engine improvements, transit agencies and the ARB can be partners in achieving new air quality benefits from the congestion relief afforded by urban transit buses.

D. Public Transit Bus Fleet Regulation Summary (title 13, CCR, sections 1956.1-1956.4)

The public transit bus regulation was designed to achieve nearer-term emission reductions of NOx through the implementation of a fleet rule. Emission reductions are accomplished through purchasing new low-emission buses and retrofitting or repowering older, higher-emitting urban bus engines to lower-emitting configurations. Long-term emissions benefits are achieved through establishing increasingly more stringent new engine standards. Consequently, new bus engines with ultra-low, near-zero, and zero-emissions will replace the older higher emitting engines over time.

An urban bus is defined as a heavy heavy-duty diesel-powered[1] passenger-carrying vehicle (+33,000 pounds gross vehicle weight rating) with a load capacity of fifteen or more passengers intended primarily for intra-city operation, i.e., within the confines of a city or greater metropolitan area (title 13, California Code of Regulations (CCR), section 1956.2). Typical features of urban buses include quick-opening exit and entrance doors and fare collection equipment. It must be noted that diesel hybrid-electric buses are considered to be urban buses although they are usually not powered by heavy heavy-duty engines.

The regulation does not apply to buses used in shuttle services, airport shuttle services, paratransit services, school transportation services and commuter services unless urban buses are used to provide those services. Buses used to provide long-distance service, that are generally equipped with luggage compartments, rest rooms, and overhead storage, are also not included.

There are two major components to the regulation: (1) a transit bus fleet rule applicable to transit agencies; and (2) more stringent emission standards for new urban bus engines applicable to urban bus engine manufacturers. The transit bus rule requires fleet operators to chose between operating a diesel bus fleet (the diesel path) or an alternative-fuel bus fleet (the alternative-fuel path) by January 31, 2001. The fleet rule contains different requirements for each path and is in effect from 2001 through 2015.

[1] A diesel-powered urban bus refers to a bus powered by a diesel-cycle engine, which by definition in the regulation includes alternative-fuel engines such as natural gas, propane, and methanol.

For both paths, reductions from the older in-use fleet are achieved through a minimum NOx fleet average emission requirement and through requirements for retrofits for PM control. The alternative-fuel path achieves equivalent NOx reductions and greater PM reductions through 2015 than the diesel path due to inherently low in-use PM emissions from alternative-fuel buses (ARB 1999b). Currently, PM emissions from alternative-fuel buses are on the order of 20 to 100 times lower than diesel buses.

The fleet rule also requires larger fleets on the diesel path to undertake a zero-emission bus demonstration project by July 1, 2003. If the project is judged to be successful by the ARB in 2006, larger fleets on both paths will be required to make zero-emission buses 15 percent of the total bus purchases beginning in 2007 for those on the diesel path and 2009 for those on the alternative-fuel path.

The current NOx emission standard for diesel, dual-fuel, and bi-fuel urban bus engines is 4.0 g/bhp-hr. Beginning with model year 2004, new urban bus engines are required to certify to a NOx standard of 0.5 g/bhp-hr through 2006, after which the NOx certification standard declines to 0.2 g/bhp-hr. An alternative approach to meeting this more stringent NOx standard is provided in the rule to allow transit agencies to purchase higher emitting engines while achieving greater NOx emission benefits through 2015. Engine manufacturers will produce engines meeting a 2.5 g/bhp-hr combined NOx plus non-methane hydrocarbon (NMHC) standard starting in 2002, and these will be available to transit agencies in 2004.

The PM standard for diesel, dual-fuel, and bi-fuel urban bus engines is currently 0.05 g/bhp-hr. The PM standard declines to 0.01 g/bhp-hr as of October 1, 2002. This standard can be met by using PM aftertreatment systems.

Low-sulfur diesel fuel is necessary for most aftertreatment technologies to function efficiently and reliably. With higher sulfur fuel, trap plugging and catalyst fouling can occur. Therefore, the transit fleet rule requires transit agencies using diesel fuel, on both paths, to purchase and use diesel fuel with a sulfur limit of 15 parts per million (ppm) beginning July 1, 2002, in order to be consistent with the PM retrofit requirements. Transit agencies with fewer than 20 buses in their active fleets that operate in federal ozone attainment areas, however, would not be subject to this requirement until July 1, 2006. Under the regulation, these fleets will also be allowed a delay in the Tier 1 and Tier 2 PM retrofit requirements until January 1, 2007, due to the projected cost and difficulty of securing delivery of low-sulfur diesel fuel in outlying rural areas before 2006.

ARB expects that the transit bus regulation will reduce NOx emissions statewide by about seven tons per day (tpd) in 2020 (ARB 1999b). Furthermore, the regulation should reduce PM emissions from urban buses by requiring new buses to meet more stringent PM standards and by requiring retrofits to reduce PM from certain portions of the older, diesel urban bus fleet. The estimated PM reduction in 2005, as a result of the PM retrofit requirements, is 300 pounds per day statewide. By 2020, the benefit from PM retrofits drops to 67 pounds per day due to the replacement of older dirtier engines with cleaner ones in earlier years.

The following points summarize the regulation (also see Table 1):

- A public transit fleet rule with two paths for compliance – a diesel path and an alternative-fuel path.
- A fuel path must be selected by transit agency by January 31, 2001.
- A 4.8 g/bhp-hr NOx fleet average requirement for transit agencies as of October 1, 2002.
- PM retrofit requirements apply on January 1, 2003 for pre-1991 MY engines. All other pre-October 2002 urban bus engines must be retrofitted following a phase-in schedule that depends on model year and fuel path.
- Zero-emission bus (ZEB) demonstration project requirements in 2003 for large transit agencies on the diesel path.
- ZEB purchase requirements beginning in 2008 for large transit agencies on the diesel path and in 2010 for large transit agencies on the alternative-fuel path.
- Requirements for transit agencies to use low-sulfur fuel (15 ppm or less) in all their diesel vehicles beginning July 1, 2002.
- Reporting requirements as a mechanism to determine a transit agency's compliance with the public transit fleet rule.
- More stringent emission standards for diesel and dual-fuel urban bus engines, including a 0.01 g/bhp-hr PM standard starting in October 1, 2002 and a 0.5 g/bhp-hr NOx standard for MY 2004-2006.
- More stringent emission standards, including a 0.2 g/bhp-hr NOx standard and a 0.01 g/bhp-hr PM standard, for all 2007 and subsequent model year engines.

TABLE 1: Comparison of Fleet Rule Requirements

Year	Diesel Path	Alternative-Fuel Path
July 2002	Require use of low sulfur fuel (15 ppm)	Require use of low sulfur fuel (15 ppm)
October 2002	NOx fleet average requirement	NOx fleet average requirement
2003-2009	Tier 1 (pre-1991) by January 1, 2003	Tier 1 (pre-1991) by January 1, 2003
	Tier 2 (1991-1995) by January 1, 2004	Tier 2 (1991-1995) by January 1, 2005
	Tier 3 (1996- pre-Oct. 2002) by January 1, 2007	Tier 3 (1996-pre-Oct. 2002) by January 1, 2009
July 2003	3 bus demo of ZEBs for large fleets (>200)	Not applicable
July 2008	15% of new buses are ZEBs for large fleets (>200)	Not applicable
July 2010	Not applicable	15% of new buses are ZEBs for large fleets (>200)

E. Implementation Outreach

In implementing this regulation, staff has worked with the regulated community to explain the new rule and answer questions about compliance. Staff prepared forms that transit agencies could use to make their initial and first annual report and has offered to continue providing reporting forms each year. Staff attended city council and transit board meetings where the issue of path selection was agendized, and if requested, staff provided explanatory testimony. Conferences also provided a valuable opportunity for outreach, and staff made presentations at the following meetings: California Transit Association conference, November 2000; SAE International Truck and Bus Meeting, December 2000; American Public Transportation Association, Alternative Fuels Committee meeting, January 2001; San Gabriel Valley Council of Governments Conference on the Environment, May 2001; and World Bus and Clean Fuel Expo, July 2001.

In 2000 and 2001, staff met on several occasions with representatives of the Engine Manufacturers Association (EMA), the California Transit Association (Cal Transit), and transit agencies to discuss specific implementation issues. For example, on August 25, 2000, staff attended a San Jose Valley Transit Association meeting. On April 18, 2001, staff met with representatives of EMA, Cal Transit, and four transit agencies in Sacramento. On May 17, staff met with representatives of three Bay Area transit agencies in San Jose. On July 24, staff met with representatives of eleven transit agencies in southern California.

Staff has also sent letters to transit agencies notifying them of deficiencies in their initial and first annual reports and worked with those transit agencies to bring them into compliance. Staff has responded to transit agencies that submitted applications for the alternative NOx emission reduction strategy with a letter and phone calls. All transit agencies that did not submit an application received a letter notifying them that they were not eligible to purchase diesel engines in the 2004-2006 MYs that exceed the 0.5 g/bhp-hr NOx emission standard, as required in title 13, CCR, section 1956.1(a)(11).

Finally, staff conducted a public workshop on implementation at our El Monte facility on April 26, 2001. Attendance included eleven transit agencies from around the state, twelve providers of services or fuel to transit agencies, two engine manufacturers, the Western States Petroleum Association, the South Coast Air Quality Management District, and the Coalition for Clean Air. A letter summarizing those remaining implementation issues was subsequently posted to our transit bus web site[2], mailed to all transit agencies in California, and was linked from the Cal Transit web site with a special notice of importance.

F. Board Directions to Staff (Resolution 00-2, February 24, 2000)

During the course of the January 2000 Board Hearing, several issues were brought up for further discussion. These issues included an alternative NOx strategy to purchasing buses that meet the MY 2004-2006 0.5 g/bhp-hr NOx standard, status of aftertreatment technologies, and hybrid-electric bus testing. At the end of the January hearing, staff was instructed to research these topics further and return with recommendations for the Board in February. After the discussion at the February hearing, the Board approved the regulation, which includes the alternative NOx strategy, and directed staff to provide regular updates on the implementation of the regulation (Resolution 00-2, Appendix A). The specific directions from Resolution 00-2 and the February Board hearing that are relevant to this update include:

1) To report to the Board regularly on transit agencies' progress in implementing the regulations;

2) To report to the Board on implementation of emission reduction strategies as an alternative to compliance with the 2004 standards. Staff was asked to analyze the first exemption application and present its recommendation before the Board as part of the first update;

3) To report on the status of advanced aftertreatment systems; and

4) To report on the progress toward development of a test procedure for the evaluation of hybrid-electric bus emissions.

This report is the first update since the public transit bus fleet regulation was adopted in February 2000.

[2] www.arb.ca.gov/msprog/bus.bus.htm

II. IMPLEMENTATION PROGRESS

Each transit agency was required to select a fuel path as part of its initial report and submit the information to the Executive Officer by January 31, 2001. Additionally, an annual report is due by January 31 of every year from 2001-2015. The annual report contains the number, model year, and fuel used for active transit buses engines owned or operated, and bus purchases and/or leases, beginning with January 1, 2001. The transit agency must also calculate its NOx emission fleet average in the annual report. If the NOx fleet average exceeds 4.8 g/bhp-hr as of January 1, 2001, then the transit agency is required to submit a schedule of planned actions to achieve that average by October 1, 2002. The schedule includes the number and model years of bus purchases, retirements, retrofits, and/or repowerings in the transit agency's active fleet as of October 1, 2002. These reporting requirements are set forth in title 13, CCR, section 1956.4.

This section summarizes and discusses the data provided by the transit agencies for the January 31, 2001, annual report and fuel path selection.

A. Fuel Path Selection [title 13, CCR, section 1956.2(c)]

Seventy California transit agencies are subject to the transit bus regulation, and all of them have selected a fuel path per the requirements of regulation. Of the 70, forty-three (61 percent) have elected to follow the diesel path while 27 (39 percent) have chosen the alternate fuel path (Table 2 and Appendix B). The total number of buses in transit agencies that chose the diesel path is 3636. Correspondingly, there are 4909 buses in the transit agencies that chose the alternate fuel path.

In the San Joaquin Valley Air Pollution Control District (SJVAPCD), eight transit agencies are subject to the regulation. Of the eight, half chose the diesel path and half chose the alternative fuel path. Fresno County Rural Transit Agency (FCRTA), Kern Regional Transit (KCT), and Taft Area Transit (TAT) submitted reports, but were not subject to the regulation either because they are rural transit providers (FCRTA and KCT) or because the buses were not powered by heavy heavy-duty engines (TAT). The agencies on the diesel path have a total of 151 buses in active service as of January 2001. This accounts for 43 percent of the total urban bus fleet in San Joaquin Valley air basin (355 buses). Fresno Area Express accounts for about 33 percent, making it the largest transit agency in the SJVAPCD.

Of the 18 transit agencies in the South Coast Air Quality Management District (SCAQMD), seven (40 percent) chose the diesel path while 11 (60 percent) chose the alternative fuel path. Of the 4076 buses in the district, 467 buses are in seven transit agencies that selected the diesel path. Although seven transit agencies elected the diesel path, all 18 transit agencies subject to the ARB regulation in the SCAQMD are required to purchase or lease alternative-fueled buses when adding to or replacing vehicles in their fleets as a requirement of the SCAQMD Rule 1192. The data provided to ARB indicates that about 60 percent of all the buses in the district are part of the Los Angeles County Metropolitan Transportation Authority (LACMTA).

In the Bay Area Air Quality Management District (BAAQMD), all but two of the transit agencies chose the diesel path, out of a total of 15 agencies. Of the 2745 buses in the district, 61 are in the two agencies that chose the alternative fuel path, while the remaining 2684 buses are spread among 13 agencies. Alameda/Contra Costa Transit (AC Transit), the largest transit agency in the BAAQMD, has 741 buses in active service. Their fleet accounts for 27 percent of the total bus fleet in that district.

In the San Diego County Air Pollution Control District (SDCAPCD), of the six transit agencies that submitted information, only one agency, National City Transit, chose the diesel path. Of the 647 buses in the air district, 12 are in service for National City while 635 are in the remaining five transit agencies. The largest transit agency in the SDCAPCD is San Diego Transit with 318 buses, representing about 49 percent of the total buses in the district.

There are two transit agencies in the Sacramento Metropolitan Air Quality Management District (SMAQMD), Folsom Stage Lines (Folsom) and Sacramento Regional Transit District (Sac RT). Folsom is on the diesel path while Sac RT is on the alternative fuel path. Of the 227 buses in the air district, 214 are in active service for Sac RT, making it the larger of the two transit agencies in the SMAQMD.

Of the remaining 21 transit agencies in 14 air districts, seventeen (81 percent) are on the diesel path and four (19 percent) are on the alternative fuel path. There are 186 buses in active service for the four transit agencies on the alternative fuel path, while the remaining 17 transit agencies have 309 buses in active service. Placer County Transportation and South County Transit submitted reports, but are exempt from the requirements of the regulation because their buses are not powered by heavy heavy-duty engines. A complete list of all the transit agencies with their fuel path selections is found in Appendix B.

TABLE 2: Fuel Path Selection and Bus Fleet Total (2001)

Air Basin	Total Agencies	Diesel Path	Number of Buses	Alternative Fuel Path	Number of Buses
San Joaquin Valley APCD	8	4	151	4	204
South Coast AQMD	18	7	467	11	3609
Bay Area AQMD	15	13	2684	2	61
San Diego County APCD	6	1	12	5	635
Sacramento Metro AQMD	2	1	13	1	214
All Others	21	17	309	4	186
Total	70	43	3636	27	4909

Many transit agencies operate a mix of diesel and alternative fueled buses in their fleets. Table 3 shows the number of buses categorized by fuel type in each air district as of January 1, 2001. Of the 6679 diesel buses, 41 percent are operated in the BAAQMD and another 41 percent are operated in the SCAQMD. In contrast, the majority of 1866 alternative fuel buses are in the SCAQMD (73 percent).

TABLE 3: Number of Diesel and Alternative Fuel Buses by Air District (2001)

Air District	Number of Diesel Buses	Percentage	Number of Alternative Fuel Buses	Percentage
San Joaquin Valley APCD	307	5%	48	3%
South Coast AQMD	2719	41%	1357	73%
Bay Area AQMD	2718	41%	27	1%
San Diego County APCD	458	7%	189	10%
Sacramento Metro AQMD	79	1%	148	8%
All Others	398	5%	97	5%
Total	6679	100%	1866	100%

B. Fleet Composition

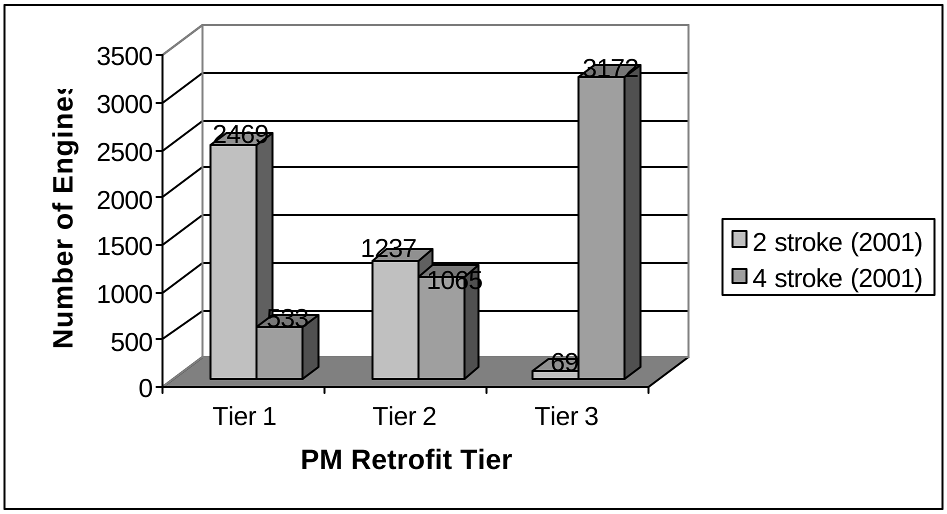
According to the January 31, 2001 submissions, there are 8545 urban buses in active service in California. Seventy-eight percent of these buses are diesel-fueled and 22 percent are alternative-fueled. In contrast, transit agencies project that there will be a total of 8912 buses in active service in October 1, 2002. Of these, 69 percent will be diesel buses while the remaining 31 percent will be alternative fuel buses. One effect of the rule, therefore, will be a shift from diesel fuel to alternative fuels, even as the transit bus population increases.

Almost all of the alternative fuel buses in 2001 use compressed natural gas (CNG), while the remaining percentage (<1 percent) use liquefied natural gas (LNG) and propane/electricity (P/E). This LNG and P/E percentage changes to 3 percent in 2002 with the projected addition of over 200 LNG buses in the fleet for the LACMTA.

The projected number of diesel buses in October 2002 is 6158. Transit agencies are required to begin retrofitting to reduce diesel PM by January 1, 2003. The PM retrofit schedule is divided into three tiers based on bus engine model year (MY). Of the 6158 diesel buses in October 2002, 23 percent (1422 buses) fall within the Tier 1 PM retrofit category (pre-1991 MY), 25 percent (1551 buses) fall within Tier 2 (1991-1995 MY), and 52 percent (3185 buses) fall within Tier 3 (1996-2002 MY).

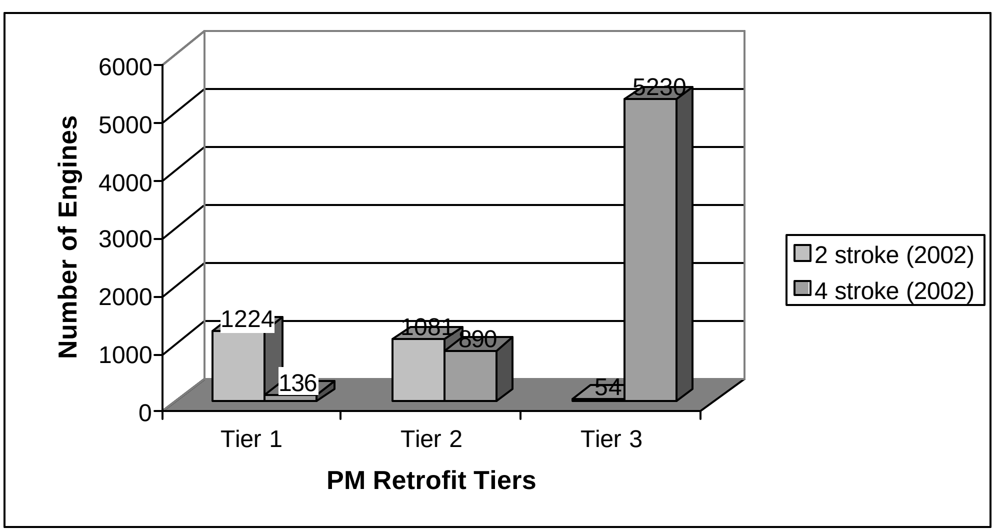
As will be discussed later, there are technological challenges associated with retrofitting two-stroke and older engines, thus it is useful to categorize engines into the retrofit tiers by age and whether they are two- or four-stroke. As of January 1, 2001, the majority of pre-1991 MY engines (Tier 1) are two stroke engines (Figure 1). There are almost an equal number of two and four stroke engines in the 1991-1995 MY engine category (Tier 2). In contrast, the post 1995 engines (Tier 3) are overwhelmingly four stroke engines.

FIGURE 1: Two and Four Stroke Engines (2001)



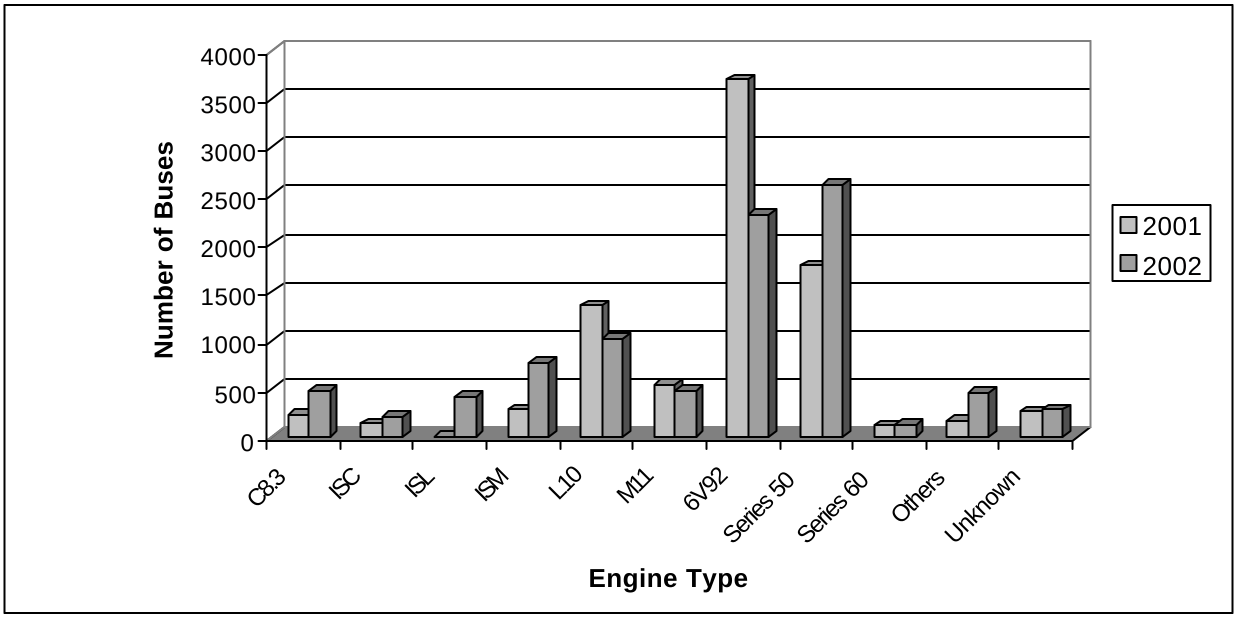
By October 2002 transit agencies have projected that they will reduce their two-stroke engines by about 50 percent and the four-stroke engines by about 75 percent for the Tier 1 category, as compared to 2001 (Figure 2). The Tier 2 two- and four-stroke engines are estimated to be roughly equal in number for 2002. Four-stroke engines are expected to increase by 65 percent according projections made by the transit agencies.

FIGURE 2: Two and Four Stroke Engines (2002)



The two major manufacturers of bus engines are Detroit Diesel Corporation (6V92, Series 50, and Series 60) and Cummins (C8.3, ISC, ISL, ISM, L10, and M11) (Figure 3). Other manufacturers of bus engines in the fleets surveyed are John Deere, Capstone, and Ford. The "unknown" category in Figure 3 includes the buses for which insufficient information was provided[3]. As the figure shows, DDC 6V92 engines make up a majority of the bus engines in 2001. In contrast, the majority of the bus engines in 2002 are projected by the transit agencies to be DDC Series 50. The reason for the shift towards more DDC Series 50 engines in 2002 is due in part to the increase in numbers of alternative fuel buses in active service for 2002. Transit agencies are also eliminating DDC 6V92 engines through repowering to other more fuel-efficient engines.

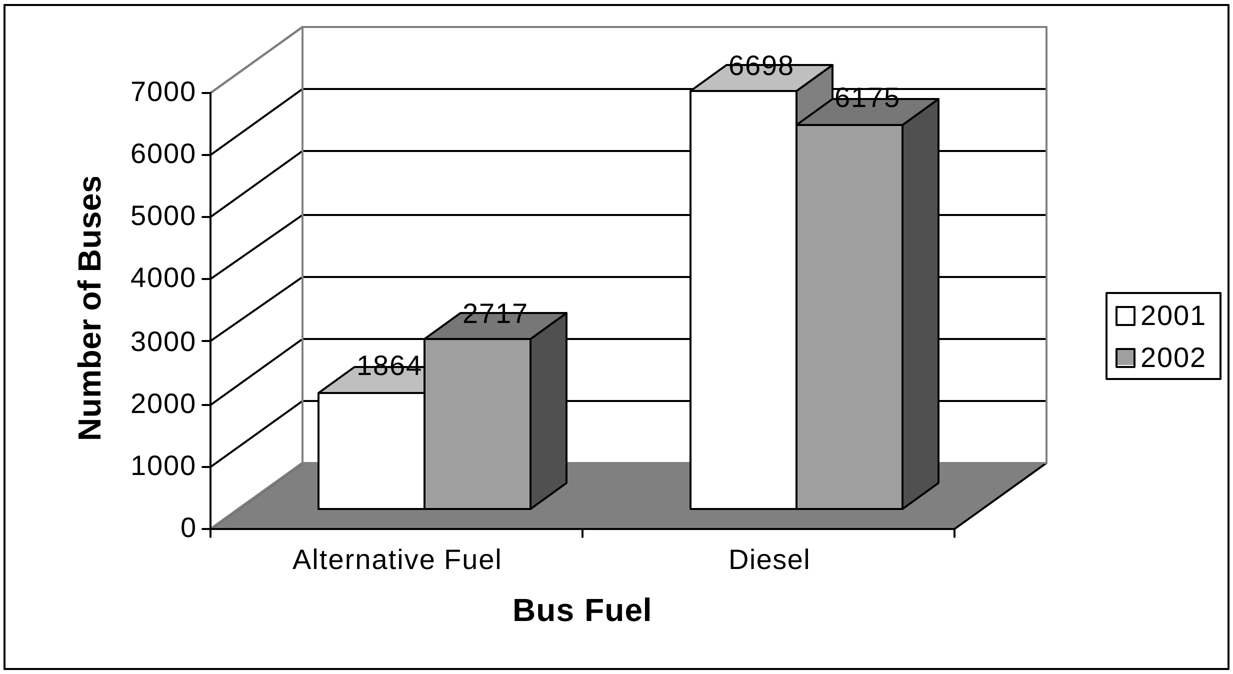
FIGURE 3: Fleet Composition by Engine Type (2001-2002)



[3] Staff has contacted the transit agencies requesting this information.

As stated earlier, transit agencies will increase the number of alternate fuel buses in their fleets by 2002, based on their submissions. Transit agencies project that the number of alternative fueled buses will increase by 48 percent in 2002 as they replace older diesel buses with new alternative fueled buses (Figure 4). Diesel engines will decrease by eight percent in 2002 as compared to 2001.

FIGURE 4: Fleet Composition by Fuel Type (2001-2002)



C. NOx Emission Average [title 13, CCR, section 1956.2(e)]

Transit agencies were required to submit their NOx fleet average, based on engine certification values, as of January 1, 2001. If the NOx fleet average was higher than 4.8 grams per brake horsepower-hour (g/bhp-hr), transit agencies were required to submit a report detailing actions planned to achieve that average by October 1, 2002. As of August 1, 2001, 68 of the 70 transit agencies subject to this rule had submitted both the 2001 and 2002 NOx fleet averages. Two transit agencies, Foothill Transit and Santa Monica Big Blue Bus, had not submitted NOx emission information for their fleets as of August 1, 2001, but staff expects to receive their data soon and will provide an update at the Board meeting on September 20, 2001.

Of the sixty-eight that submitted data, twenty-four (35 percent) of the agencies are already in compliance with the 4.8 g/bhp-hr NOx fleet average as of January 1, 2001. Forty-four (65 percent) of the transit agencies must make changes to their fleets to comply with the NOx fleet average by October 1, 2002. Staff analyzed the data submitted by those agencies and found that, contrary to their submissions, 12 agencies of the 44 transit agencies will continue to exceed the NOx fleet average as of October 2002 (Appendix C). The reasons for the fleet average exceedances include using incorrect NOx emission values in the calculations and calculating the fleet average using NOx emission values of buses that do not meet the definition of an urban bus.

One transit agency, Monterey-Salinas Transit, submitted data that indicated it would continue to exceed the 4.8 g/bh-hr NOx fleet average. As of August 1, 2001, staff has received no explanation for this transit agency's failure to comply and has contacted it for further information. Staff will provide an update to the Board if new information is received prior to the September 20, 2001, public meeting.

In addition, all of the non-complying transit agencies have been informed that they will exceed the 4.8 g/bhp-hr NOx standard for October 1, 2002. Staff will work with these transit agencies to assist them in moving towards compliance. In order to comply, these agencies would most likely need to retire additional numbers of older buses.

III. ALTERNATIVE NOx STRATEGY [title 13, CCR, sections 1956.2(c)(8) & (d)(7)]

The new engine standards applicable to manufacturers are set forth in title 13, CCR, section 1956.1. The regulation prohibits transit agencies from purchasing transit bus engines during model years 2004 through 2006 that exceed a NOx emission standard of 0.5 g/bhp-hr. Prior to regulation adoption, however, a representative of the Engine Manufacturers Association (EMA) stated that the members might be unwilling to invest in technology to meet the 2004-2006 MY NOx emission standards (ARB 2000a, p. 314). With input from the EMA, ARB staff developed an alternative strategy that the transit agencies can follow in order to comply with the regulation if they plan on purchasing buses.

The alternative NOx strategy applies to the purchase of diesel and dual-fuel engines by transit agencies on either fuel path and is set forth in title 13, CCR, sections 1956.2 (c)(8) and (d)(7). It allows transit agencies the option to apply to the Executive Officer for an exemption by June 30, 2001, from purchasing engines that meet the 2004-2006 MY engine emission standards if specified criteria are met. Transit agencies that are approved for the exemption may purchase 2004-2006 MY diesel engines with certified NOx emissions higher than 0.5 g/bhp-hr NOx. The exemption is the only mechanism allowed by the law for transit agencies to purchase non-complying diesel engines during those three years. Alternatively, there is no requirement that transit agencies must purchase buses during 2004-2006, so compliance could be achieved by not purchasing any diesel buses .

The rule has three parts. First, each transit agency that needs an exemption must have applied by June 30, 2001 (title 13, CCR, sections 1956.2(c)(8)(A) and (d)(7)(A)). Transit agencies that do not apply will not be able to purchase new diesel engines during the three year time period unless the engine meets the standards.

Second, the transit agency must demonstrate to the Executive Officer that it will achieve NOx emissions benefits through 2015 greater than would have been achieved through compliance with the engine standard (title 13, CCR, sections 1956.2 (c)(8)(B) and (d)(7)(B)). Transit agencies can modernize their fleets through scrapping older engines and repowering with newer engines. Retirement of the oldest buses in their fleets is another method to achieve compliance. During the February 24, 2000, Board hearing, the Board discussed how to define what "greater than" means in the context of the transit agencies' exemption applications (ARB 2000b, pgs.40-43). The Board directed staff to analyze the exemption applications and report back. At that time, the Board expects to clarify what "greater than" means and "establish a definition and a standard" (ARB 2000b, p.43).

Finally, before granting the exemption, the Executive Officer must make a finding that transit agencies, after consultation with the EMA, are demonstrating, or have contracted to demonstrate, advanced NOx aftertreatment technology (title 13, CCR, sections 1956.2 (c)(8)(C) and (d)(7)(C)).

A. Analysis of Exemption Applications

As of the June 30, 2001, deadline, 15 transit agencies had submitted requests for an exemption (Appendix D). Of the 15, AC Transit, Golden Gate Bridge Highway and Transportation District (Golden Gate Transit), and Santa Clara Valley Transportation Authority (VTA), submitted one or more plans to demonstrate greater NOx reductions through 2015. A fourth agency, Montebello Bus Lines, submitted an incomplete plan with no baseline data, thus the plans could not be analyzed. Some of the transit agencies have verbally or in writing requested additional time to prepare and submit plans. In addition, between June 30 and August 15, 2001, staff has received one letter and several verbal requests by transit agencies that would like to submit late exemption applications. None of the agencies submitted documentation stating that they are demonstrating NOx aftertreatment technology or have contracted to do so, as required by regulation in order to receive the exemption.

The non-responding agencies, along with those for whom the exemption is denied by the Executive Officer, will not be allowed to purchase 2004-2006 MY diesel buses that have certified NOx emissions higher than 0.5 g/bhp-hr. Staff has issued a letter to these 55 transit agencies notifying them that because they did not submit an exemption application by June 30, 2001, they will not be able to purchase MY 2004-2006 diesel-fueled buses with emissions exceeding the certification standard of 0.5 g/bhp-hr NOx. The transit agencies may purchase alternative-fuel buses or make no bus purchases at all.

The major issue expressed in personal conversations by many transit agencies that have applied for an exemption is that they believe the burden for meeting the NOx standards should be on the engine manufacturers, not on the transit agencies. In addition, many are unsure of the technologies that will be available during this time period and are, therefore, unable to suggest a plan at this time for achieving greater emission benefits. Staff will be working with all the transit agencies that submitted requests for exemptions, especially with the twelve that were unable to provide a plan in order to achieve the required emission reductions.

1. Santa Clara Valley Transportation Authority (VTA)

VTA submitted four plans plus a baseline plan in its application (Appendices D-H). Its baseline plan is defined as the plan of scheduled purchases, retirements, and/or repowerings of buses that the transit agency would have pursued if engines that meet the emission standards were available. VTA's baseline plan includes the purchase of 14 MY 2004-2006 engines that meet the 0.5 g/bhp-hr NOx emission standard. The first plan, Option A, is characterized by the repowering of 91 MY 1992 buses to 2002 NOx engine standards (2.5 g/bhp-hr NOx + NMHC), the purchase of at least 3 fuel cell buses each year from 2003-2015, and 14 new buses to be purchased in 2005. The second plan, Option B, is the same as Option A with the addition of the retirement of 576 older buses. The third plan, Option C, involves the same features as Option A, but there will be no purchase of buses during 2004-2006. Finally, the fourth plan, Option D, entails the replacement of all the buses in the fleet with new fuel cell buses starting in 2007.

Staff analyzed the plans to determine if any of them meet the requirement of demonstrating greater NOx emission benefits through 2015. Options C and D do not require approval by the ARB prior to implementation because no engines will be purchased during 2004-2006. Options A and B were analyzed by calculating NOx emission values (NOx Value), which are proportional to actual NOx emissions per year. For the purpose of these calculations, the vehicle miles traveled per bus, horsepower of the engines, and engine load were all assumed to be the same for every bus. Thus the numbers calculated are not the actual NOx emissions, but they are proportional to the actual NOx emissions.

For Option A, the NOx Values are lower than the baseline for 2002 through 2006 (Table 4). This trend reverses beginning in 2007 and continues through 2015 with larger NOx values for each year as compared to the baseline. Option A shows a net NOx Value difference of –310, which is a net NOx emission reduction of 1 percent for the 15 years.

For Option B, the NOx values are lower than the baseline from 2002 to the end of 2011 (Table 4). From 2012 on, the NOx Values for Option B are higher than the baseline plan. Option B shows a net NOx Value difference of –768, which is 2.5 percent below the baseline. Overall, the NOx Values for Option B are lower the Option A for 11 out of the 15 years analyzed.

Table 4: VTA Alternative NOx Strategy Plans Analyses

Year	Baseline NOx Value	Option A NOx Value	Difference	Option B NOx Value	Difference
2000	3275	3275	0	3275	0
2001	3093	3093	0	3093	0
2002	2533	2442	-91	2442	-91
2003	2533	2442	-91	2442	-91
2004	2474	2383	-91	2383	-91
2005	2594	2418	-176	2334	-260
2006	2594	2418	-176	2334	-260
2007	1697	1732	35	1676	-21
2008	1697	1732	35	1676	-21
2009	1697	1732	35	1676	-21
2010	1314	1349	35	1293	-21
2011	1314	1349	35	1293	-21
2012	1130	1165	35	1163	32.6
2013	1130	1165	35	1163	32.6
2014	1130	1165	35	1163	32.6
2015	930.8	965.8	35	963.4	32.6
Sum	**31135**	**30825**	**-310**	**30367**	**-768**

In summary, two plans, Options C and D, submitted by VTA did not require approval due to the absence of bus purchases in 2004-2006. The analyses of Options A and B indicated emission benefits through 2015, compared to the baseline.

2. AC Transit and Golden Gate Transit

As of August 1, 2001, staff has been unable to analyze the plans submitted by AC Transit and Golden Gate Transit because the transit agencies submissions were incomplete. Staff has contacted both agencies to request the missing data and will provide a detailed analysis at the Board meeting if possible.

3. Other Transit Agencies

The twelve transit agencies that did not submit plans with their exemption requests have asked for assistance and additional time to formulate and submit plans. Staff has contacted each of these transit agencies and will work with them if the Board directs staff to extend the deadline for plan submission.

B. NOx Aftertreatment Demonstration Status

As noted above, one requirement of the exemption application is that the Executive Officer must find the transit agencies, “after consulting with the Engine Manufacturers Association,” have demonstrated or are contractually committed to demonstrate, advanced NOx aftertreatment technology. This section of the report addresses the demonstration of advanced NOx aftertreatment technology.

According to staff, and as recorded in the transcript for the February 24, 2000, Board hearing, the EMA’s proposal included a commitment by the engine manufacturers to implement a demonstration program of buses equipped with control technology designed to meet the 2004 standards. Staff emphasized at the February hearing that the demonstration would be a precondition of any transit district obtaining approval of an alternative plan (ARB 2000b, p.14). EMA was unable to testify at the February hearing because the record for public record was closed, but the EMA comments on the 15-day Notice stated that “with one notable modification (the “equivalent” versus “greater than” reductions issue . . .), <u>the EMA proposal was adopted by the Board</u> to be included in the 15-day Notice” (EMA 2000, p.3; emphasis added). Staff, therefore, understood that the EMA had committed its members to providing a demonstration of advanced NOx aftertreatment technology.

Staff contacted representatives of the EMA and the transit trade association, Cal Transit, in March 2001 to discuss implementation issues. In April 2001, staff met with both EMA and Cal Transit to discuss implementation issues, including the requirement for a NOx aftertreatment demonstration. Conversations continued in May, June, and July regarding the status of advanced NOx aftertreatment. Staff has been told that EMA and its members have no demonstrations planned specifically for transit buses, although they are working on NOx aftertreatment for heavy heavy-duty engines. EMA’s members stressed to staff that they are supportive of NOx aftertreatment to meet future (i.e., 2007-2010) NOx emission standards.

It must be noted that the United States Environmental Protection Agency's (U.S. EPA) NOx standards, which were slated for implementation in 2007at the time the Board adopted the transit bus regulation was adopted, have now been finalized for 2010. This change translates into a delay of early demonstration programs, so NOx emission controls are not yet available to transit agencies.

Staff also asked the Manufacturers of Emissions Control Association (MECA) representatives and members for an update to determine the status of NOx aftertreatment technology for mobile heavy heavy-duty engines. A discussion of the status of advanced NOx aftertreatment technology is found in Chapter IV of this report. As far as staff is aware, only one California transit agency has been moving forward to test a NOx aftertreatment system. Torrance Transit System, which has not applied for the alternative NOx strategy exemption as of August 15, 2001, is working with Extengine Transport Systems LLC and KleenAir Systems Inc. to install and test their technology on two transit buses, a diesel-electric hybrid bus and a conventional diesel bus. The system uses a computer-controller to inject ammonia into the exhaust stream to convert NOx into nitrogen and water through selective catalytic reduction (SCR). Thus far, this NOx aftertreatment system has only been tested on stationary engines using a 13-mode steady-state duty cycle. There is not yet adequate data to determine if this system is capable of achieving the degree of NOx reduction needed to comply with the 2004 or 2007 bus emission standards. Thus, the determination of this system as a possible vehicle for compliance with the NOx aftertreatment demonstration requirement must be delayed until further data are collected.

C. Summary and Recommendations

As of June 30, 2001, staff received 15 applications for exemption under title 13, CCR, section 1956.2 (d)(7) for transit agencies on the diesel path. No transit agency on the alternative fuel path applied for exemption under title 13, CCR, section 1956.2 (c)(8). Of the 15, three submitted plans to demonstrate how they would achieve NOx emissions benefits greater through 2015 than would have been achieved through compliance with the 2004 though 2006 MY engine standard of 0.5 g/bhp-hr.

As of August 15, 2001, VTA was the only transit agency to submit a complete plan. Staff analyzed their two options that included purchase of diesel MY 2004-2006 buses and concluded that both demonstrated greater NOx emission benefits through 2015, as required by the regulation, and provide a good framework that can be followed by other transit agencies. The other 14 transit agencies that submitted an application for exemption requested additional time and assistance in preparing plans, or needed to submit more information before their plans can be assessed. In addition, between June 30 and August 15, 2001, staff has receive one letter and several verbal requests by transit agencies that would like to submit late exemption applications.

None of the transit agencies that applied for exemptions as of June 30, 2001, indicated that they were demonstrating or contracted to demonstrate advanced NOx aftertreatment technology. This is an important requirement of the exemption regulation and is necessary to help ensure viability of the technology for meeting the 2007 engine exhaust standards. However, the national NOx standards which were slated for implementation in 2007, when the transit bus regulation was adopted, have now been finalized for 2010. This change translates into a delay of early demonstration programs, so NOx emission controls are not yet available to transit agencies.

- Staff recommends that the Board direct the Executive Officer to allow transit agencies that applied for an exemption and submitted a plan demonstrating greater NOx benefits through 2015 additional time to demonstrate advanced NOx aftertreatment technology. The schedule staff recommends is as follows: transit agencies must commit resources to a demonstration project as of March 31, 2002, and advanced NOx aftertreatment demonstrations must be in progress as of March 31, 2003.

- Staff further recommends the Board allow each transit agency the option of performing the demonstration individually or jointly. If the transit agencies elect a joint project, then the demonstration must include at least three buses and demonstrate NOx aftertreatment technology that will offer commercial potential (i.e., lower NOx emissions by 70-90 percent). Transit agencies that elect individual demonstrations shall include at least one bus.

IV. AFTERTREATMENT TECHNOLOGY STATUS UPDATE

Pursuant to Resolution 00-2, the Board requested that staff provide an update on the status of advanced aftertreatment systems. In this chapter, staff summarizes and discusses the status of PM and NOx aftertreatment technologies. This section only discusses how retrofit technologies reduce NOx and PM, although other pollutants such as carbon monoxide (CO) and HC may also be significantly reduced through these emission control systems.

A. Advanced PM Aftertreatment Technology

Retrofit technologies are available to reduce emissions from the existing urban bus fleet by 85 percent, to below 0.01 g/bhp-hr PM in some cases. A retrofit involves a hardware modification to an existing engine to reduce its emissions from the standards to which it was originally certified. Emission control systems for PM reduction primarily operate through trapping or filtering particulates and incinerating them.

1. Diesel Particulate Filter

A diesel particulate filter (DPF) is positioned in the exhaust stream to trap or collect a significant fraction of the particulate emissions while allowing the exhaust gases to pass through the system. Since the volume of particulate matter generated by a diesel engine is sufficient to fill up and plug a reasonably sized filter over time, a means of disposing of the trapped particulate ("regeneration") must be provided. The most common means of disposal is to oxidize or burn the particulate in the filter for further substrate use. To facilitate filter regeneration on diesel engines in real operation, the exhaust gas temperature has to be increased or the soot ignition temperature has to be lowered using a catalyst (DieselNet 2001a). Filter systems do not appear to cause any additional engine wear or significantly affect vehicle maintenance (MECA 1998).

Several promising passive particulate filter technologies are Johnson Matthey's Continuously Regenerating Technology (CRT™) DPF and Engelhard's DPX™ catalytic particulate filter. The CRT™ combines a platinum-based catalyst with a filter element. The catalyst oxidizes NO to NO_2 and uses the produced NO_2 as an oxidant to remove the PM trapped in the filter material following the catalyst. The CRT™ requires the use of low-sulfur diesel fuel (less than 15 ppm sulfur). Engelhard manufactures different DPX™ PM systems that can work at different fuel sulfur levels, including the current California diesel fuel. It should be noted that higher particulate removal efficiency is achieved with lower fuel sulfur content. Several other manufacturers are also developing passive PM filters.

Programs are underway to evaluate the correlation between levels of sulfur in diesel fuels and the effectiveness of retrofit (both PM and NOx) devices. In one demonstration program, BP/ARCO is testing its low sulfur diesel fuel, ECD-1, on catalysts and particulate filters made by Johnson Matthey and Engelhard. ECD-1 contains a maximum of 15 ppm sulfur. The first round of emission results from the BP/ARCO demonstration program indicate that PM, HC, and CO are reduced by greater than 90 percent (LeTavec 2001). A second round of emission tests is currently underway.

The Clean Diesel Demonstration Program conducted by New York City Transit (NYCT) tested the results of using PM retrofits on urban buses (MTA NYCT 2001). The program was designed to test the emissions using these systems: (1) original engine manufacturer (OEM) catalyst using 350 ppm sulfur diesel fuel; (2) OEM catalyst using 30 ppm sulfur diesel fuel; and (3) Johnson Matthey's Continuously Regenerating Technology (CRT™) particulate filter using 30 ppm sulfur diesel fuel.

The conclusions drawn from this study were: (1) the use of the ultra-low sulfur diesel fuel alone resulted in a 76 percent average reduction in the total HC, 29 percent average reduction in CO, and 29 percent average reduction in PM; and (2) the CRT™ resulted in 93-98 percent reductions in total HC, CO, and PM, using the New York Bus Cycle. The CRT™ testing will continue until November 2001. Confident in the results of this program, NYCT has contracted for ultra low sulfur diesel fuel for its entire fleet for the next three years starting in September 2000. NYCT has also committed to retrofitting 100 percent of its fleet by 2003 (MTA NYCT 2001). Diesel particulate filters have been retrofitted in 550 buses as of August 2001 (Dana Lowell, personal communication, 2001).

Passive systems rely on the heat of the exhaust, usually with the aid of a catalyst, to combust the PM at a higher average rate than the rate at which the PM is accumulated. Thus, the applicability of passively regenerating diesel particulate filters may be limited to applications with moderate to low engine-out PM emissions and higher exhaust temperatures. Although these conditions typically encompass late-model buses, they do not include all buses. For example, older two-stroke engines are likely to require different control strategies. For those and other applications in which the engine-out PM level is relatively high, and the exhaust temperatures are relatively cool, actively regenerating systems are more appropriate. Active systems typically use an external source of heat to oxidize the particulate matter. The most common methods involve electrical regeneration by passing a current through the filter medium, injecting fuel to provide additional heat for particle oxidation, or the use of a fuel-borne catalyst or other reagent to initiate regeneration. Off-road applications of these active systems have been implemented in Europe since the early 1990's (Mayer and Wyser 2001). However, it should be recognized that passive systems are the most attractive from a user's standpoint as they require the least amount of maintenance.

2. Diesel Oxidation Catalyst

A diesel oxidation catalyst (DOC) transforms pollutants into harmless gases by means of oxidation. The precious metal catalyst oxidizes CO, gaseous HC, and the liquid HCs adsorbed on the carbon particles present in diesel exhaust gases. The liquid HCs are referred to as the soluble organic fraction (SOF). The SOF is one component of the total PM in exhaust emissions. Oxidation catalysts can reduce the SOF by 90 percent under certain operating conditions (MECA 1998), and according to staff estimates, could reduce total particulate emissions by greater than 30 percent.

Oxidation catalysts have proven effective in achieving modest PM emission reductions on older buses. Under the U.S. EPA's urban bus rebuild/retrofit program, five manufacturers (Detroit Diesel Corporation, Engelhard, Johnson Matthey, Twin Rivers

Technologies, and Engine Control Systems) have certified diesel oxidation catalysts as providing at least a 25 percent reduction in PM emissions (U.S. EPA 2001; MECA 1998).

The Diesel Emission Control – Sulfur Effects (DECSE) Program is a joint government/industry program created to investigate the effects of diesel fuel sulfur levels on emission control systems such as diesel oxidation catalysts. Two DOCs (low and high temperature catalysts) were tested before, during, and after a 250-hour aging cycle using four different sulfur level diesel fuels (DECSE 2001). The reduction efficiencies for HC, CO, and PM were evaluated. Results from this study indicated that fuel sulfur level does not significantly affect performance degradation. Some performance loss, however, was noted as early as 250 hours after initial installation. Other results from the same study showed that low sulfur diesel fuel is needed if a DOC is to be used as an efficient emission control device.

3. Technology Evaluation

Prior to its use in any transit bus, ARB requires that a retrofit device be verified to reduce diesel particulate matter emissions by 85 percent or, alternatively, to levels of 0.01 g/bhp-hr or below (title 13, CCR, section 1956.2(f)(7)). The ARB staff is currently developing regulations regarding the evaluation of retrofit devices. In recognition of the major role that retrofit technologies must play in the reduction of public exposure to diesel PM, the staff has also provided an interim mechanism to verify emission reductions (ARB 2001b).

The verification process is intended to ensure that retrofit devices provide the necessary reductions while remaining durable. Prior to a device being verified, the manufacturer must provide a general description of the emission control system, including the principles of operation; effects on engine performance and fuel consumption; any fuel requirements (e.g., diesel fuel with a sulfur level of 15 ppm or less); and maintenance requirements. In addition, the manufacturer must provide emissions test data and durability data. Devices intended for heavy heavy-duty engines, such as those used in transit buses, must show a durability of 150,000 miles.

Installation of emission control equipment to the exhaust system of the vehicle may result in increases in back pressure. The manufacturer must therefore demonstrate that the resulting back pressure is within the engine manufacturer's specified limits, or will not result in any damage to the engine.

To ensure acceptability to the user, the manufacturer must provide a warranty against extensive emissions defects. In addition, the manufacturer must clearly specify in the owner's manual the following information:

- Warranty statement including the warranty period over which the manufacturer is liable for any defects;
- Installation and maintenance requirements for the emission control system;
- Fuel consumption penalty, if any;

- Fuel limitations, if any (e.g., sulfur content);
- Emission control system maintenance requirements; and
- Contact information for the manufacturer of replacement components, cleaning agents, and/or disposal sites.

As of August 2, 2001, staff has verified two particulate control devices for retrofit on urban bus engines and other applications (Appendix I). The Engelhard DPX™ is verified for certain engine families of 1995 to 1997 MY Cummins M11 and 1998 to 2001 MY Cummins ISM engines. The Johnson Matthey CRT™ is verified for certain engine families of 1999 to 2000 MY DDC Series 50 bus engines. Verifications are based both on model year and engine family. Additional verifications are expected shortly.

4. Implications of Retrofit Requirements

As discussed above, as of August 2, 2001, two particulate control devices have been verified, and these have application only for newer model engines. Title 13, CCR, section 1956.2 (f), however, requires that older engines be retrofitted to reduce diesel PM earlier than newer engines. Specifically, 100 percent of pre-1991 MY diesel engines must be retrofitted with technology will reduce diesel PM by 85 percent by January 1, 2003. The same requirement applies to a lower percentage of MY 1991 through 1995 engines in January 2003 under a phase-in period. The deadline for full compliance is January 1, 2004 for transit agencies on the diesel path and January 1, 2005 for transit agencies on the alternative-fuel path. In general, two-stroke bus engines are more technologically challenging to retrofit with a passive DPF because PM emissions tend to be higher than 4-stroke engines. Furthermore, the exhaust gas temperature may not meet the minimum temperature required for spontaneous regeneration.

The regulation does provide for a one-year implementation delay if a retrofit device is not or will not be available to meet the requirements within six months of the dates specified. Staff will evaluate the status of the technology and determine whether or not a delay will be necessary. If an implementation delay is issued to transit agencies, staff will assess the technology to determine any actions that may be necessary beyond the one-year delay. Staff will complete its assessment and advise the Board of its findings by July 2002.

B. Advanced NOx Aftertreatment Technology

Controlling NOx emissions from diesel engine exhaust is inherently difficult because the oxygen-rich exhaust environment of diesel engines makes reduction, the removal of oxygen, difficult to achieve. Separation of the nitrogen and oxygen molecules in NOx requires a reductant (HC, CO, or H_2), which is present in low concentrations in diesel exhaust. Three-way catalysts used on spark-ignited engines cannot be used in diesel engines to control NOx because the high concentration of oxygen at all operating conditions interferes with NOx reduction (Diesel Net 2000c).

Catalyst technologies to reduce NOx from diesel exhaust are either still under development or at an early state of commercialization (DieselNet 2000c). These technologies include selective catalytic reduction, lean-NOx catalyst, NOx adsorber, plasma technology, and exhaust gas recirculation. Of these, exhaust gas recirculation technology is commercially available for mobile sources today. Selective catalytic reduction is used commercially in stationary sources, but applications in mobile sources are still challenging. Manufacturers are focusing research and development on achieving significant NOx emission reductions in the 2007 to 2010 time frame, as required by U.S. EPA regulations. Research and development for in-use heavy-duty vehicle retrofit systems appears to be a much lower priority for manufacturers.

1. Selective Catalytic Reduction of NOx

Selective catalytic reduction (SCR) uses a reductant, usually urea or ammonia, to convert NOx to harmless gases. The reducing agent is injected into the exhaust upstream of a catalyst bed. As the exhaust gases and the reductant pass over a catalyst applied to either a ceramic or metallic substrate, NOx emissions can be reduced to gaseous nitrogen and water vapor. This reaction is promoted by the catalyst over the competitive reaction of ammonia with oxygen (Diesel Net 2000c).

SCR has been used for many years in industrial processes, as well as on stationary engines, and some marine applications, with much success. The use of SCR on diesel trucks and buses, however, has not achieved the same success because of the complexity required of the system, large size, safety concerns, and issues of control of the reductant. Mobile diesel engines operate under transient duty cycles, with variations in exhaust temperature, exhaust gas flow, and NOx concentration, making the injection of the reductant difficult to time properly. Improper timing and quantity of reductant injection can result in undesirable ammonia and ammonium nitrate particulate emissions (Diesel Net 2000b).

Several studies in heavy-duty engines have estimated that SCR efficiencies can range from 50-80 percent or even higher (Tim Johnson, personal communication, 2001). In addition to reducing emissions of NOx, SCR simultaneously reduces emissions of HC by 50 to 90 percent and PM by 30 to 50 percent (MECA 2000a). In general, higher efficiencies, however, have been reported on steady-state cycles. Attaining high efficiencies from mobile engines operating on transient duty cycles is more challenging. In a recent ARB sponsored demonstration project, two SCR systems were able to achieve 75 percent reduction in NOx emissions on the transient cycle Federal Test Procedure during bench testing with a DDC Series 60 engine. Valuable information was gained from the project regarding SCR system readiness, SCR system installation and durability, and urea infrastructure and availability. The project had to be halted before demonstration on an in-use truck due to the need for further catalyst/engine system development (Cackette 2001). Although SCR technology is very promising from the standpoint of achieving high control levels of NOx, the application to mobile sources remains very challenging.

2. Lean NOx (DeNOx) Catalyst

A lean NOx catalyst works by using the HC in the exhaust gas stream as a reducing agent for NOx. The type of catalyst used depends on the temperature at which the NOx catalyst will operate. Two common types of catalysts with their respective temperature ranges are platinum (200-250°C) and copper (450-500°C). The ideal operating condition for these catalysts is a high HC to NOx ratio in the exhaust gas. Because the ratio of HC to NOx is relatively low in diesel exhaust, additional fuel may be added to the exhaust gas to increase the HC/NOx ratio. This practice, hydrocarbon supplementation, allows catalysts to achieve higher efficiencies, but also decreases the fuel economy (Mark and Morey 1999).

The limitations of this technology, such as narrow operating temperature windows, insufficient durability at high temperatures, and sulfur intolerance, are mainly due to the catalysts. Current catalysts are not effective enough in reducing NOx to nitrogen as opposed to reducing NOx to nitrous oxide (N_2O). High sulfur levels in fuel can decrease the effectiveness of a NOx catalyst by removing catalytic active sites (Majewski 2001a).

The major drawback to the commercialization of lean NOx catalyst systems for new engines is that the NOx reductions achieved are too low to be used to achieve future NOx emission standards. Realistic levels of NOx reduction range from 10-20 percent without any fuel penalty and 20-30 percent with 5-7 percent reduction in fuel economy (Tim Johnson, personal communication, 2001). Commercial applications have primarily been confined to combination with other technologies, such as oxidation catalysts and particulate filters. The now-defunct company Ceryx incorporated a lean NOx catalyst in their “QuadCAT” system. Unfortunately, the QuadCAT was not optimized before the company went out of business.

3. NOx Adsorber

A NOx adsorber or trap adsorbs and stores NOx in a catalyst washcoat during lean driving conditions. The NOx is released under rich operation when it is catalytically converted to N_2. Regeneration and conversion of NOx occurs during hydrocarbon supplementation, thereby creating a reducing environment. Systems tested to date are not thermally durable and are sensitive to ultra-low sulfur fuel (Duo and Bailey 1998).

NOx adsorber catalysts have exhibited high NOx conversion efficiencies, in excess of 80 to 90 percent and considerable effort is being invested in further developing the technology. Issues under research include developing catalyst formulations and on-vehicle configurations that improve low temperature performance; sulfur trap technologies that allow for lower temperature sulfur removal; and improvements in sulfur resistance (MECA 2000b). A research program conducted by the U.S. Department of Energy concluded that over 80 percent peak conversion efficiency could be achieved with a fuel economy penalty of less than four percent (DECSE 1999). NOx adsorbers are perceived by many as the diesel NOx control technology of the future (Majewski 2001b).

4. Plasma Exhaust Technology

Non-thermal plasma in exhaust gas has the potential to reduce both NOx and PM in diesel exhaust (DieselNet 2000d). The non-thermal plasma must be used in combination with catalysts, such as a lean NOx or SCR catalyst, to achieve the reductions. When used alone, plasma is not a viable NOx control method because it is an oxidizer. Non-thermal plasma is a low temperature gas stream with excited electrons that have a higher kinetic energy than the background gas. The plasma helps to achieve NOx reductions by converting NO to NO_2. This enhances the efficiency of the catalyst because lean NOx or SCR catalysts are most efficient when NO_2 is the main component of NOx. Diesel exhaust normally contains about 70-90% NO and the remaining is NO_2.

The limitations associated with the plasma-assisted catalysis include packaging, durability and a narrow temperature window of the specific catalyst material. In laboratory and bench-scale research, plasma-catalyst systems are achieving 60-70 percent NOx reduction at 6-8 percent fuel penalties (Tim Johnson, personal communication, 2001). Plasma exhaust treatment requires considerable research and development before it will be a commercially viable technology (DieselNet 2000d).

5. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) returns a portion of the engine's exhaust to the combustion chamber via the inlet system (DieselNet 2001e). This method involves displacing some of the oxygen inducted into the engine as part of its fresh charge air with inert gases, thus reducing the rate of NOx formation. Limitations of EGR are substantial and include increasing emissions of PM, HC, and CO as well as decreasing the fuel economy and causing potential premature engine wear and durability problems. The proper balance of EGR and temperature may provide the proper characteristics necessary for decreasing NOx emissions without increasing PM emissions.

EGR technology is available commercially in the DDC Series 50EGR heavy heavy-duty diesel engine. The technology, as it is used in the DDC Series 50EGR engine, does not offer significant NOx reduction currently. Future developments in cooled EGR technology hold the potential for much greater NOx reductions. By cooling the exhaust gas before it is introduced into the combustion chambers, the rate of NOx formation can be greatly reduced.

V. HYBRID-ELECTRIC BUS TESTING

Hybrid drivetrain technology for light-duty vehicles has been under development for many years. The benefits of hybrid drivetrain technology have already been demonstrated by the high fuel economy of the passenger cars Toyota Prius and Honda Insight, ranging from 40-50 miles per gallon. More recently, transit bus fleet operators have been investigating the use of hybrid technology for urban bus applications for various reasons. First, a typical hybrid design incorporates the use of a Renewable Energy Storage System (RESS), such as a battery pack, to provide occasional added power for accelerations or hill-climbing demands. Second, the use of a RESS allows for a considerably smaller engine than the conventional diesel engine, allowing for better fuel economy. Third, efficiency gains are made with the re-capture of electrical energy during regenerative braking. For example, a transit bus operating on a typical route performs many short trips with a considerable number of stops for passenger pick-up and drop-off. This type of driving pattern has an unusually high number of braking events. These braking events are well suited for hybrid drivetrains that allow for the recapture of braking energy into the RESS and a large decrease in conventional braking system wear and tear. Finally, hybrid technology can provide reduced emissions of all criteria pollutants.

The Board recognized the potential for emission benefits of hybrid-electric technology, and thus, has approved diesel hybrid-electric vehicles for Carl Moyer funding. Until test procedures for hybrid-electric vehicles are available, the ARB will evaluate each project on a case-by-case basis (ARB 2000e, p.22).

A. Need for New Heavy-Duty Hybrid-Electric Vehicle Certification Procedures

Currently, heavy-duty engines are certified in California and by the U.S. EPA using an engine-only dynamometer and a standardized load cycle. This methodology has been used for many years for conventional engines and relates driving speed directly to a particular engine load. The conventional test methodology is not appropriate because the hybrid design decouples the engine from the drive wheels. Secondly, a hybrid-electric engine is typically smaller than a conventional engine; therefore, the results of the current dynamometer test would yield results that cannot be comparable to other engines used for similarly sized vehicles. Furthermore, a hybrid engine is typically designed to operate within a narrower power-demand range than a conventional engine because of the added power available from the RESS. The traditional engine-only certification procedure does not evaluate the complete emissions benefits of heavy-duty hybrid-electric vehicles (HEV).

The ARB and U.S. EPA use the transient engine test cycle for heavy-duty engine certifications. Staff must therefore identify existing appropriate driving schedules or, if necessary, develop new driving schedules applicable to heavy-duty transit bus operations. Staff expects that the driving schedules will be based on currently available driving cycles. Although these cycles have been developed for other purposes, they may have applicability to hybrid bus certification as well. The heavy-duty hybrid transit bus certification process should sufficiently represent actual in-use driving to allow for direct comparisons between hybrid, conventional diesel, and alternative-fueled transit bus technologies.

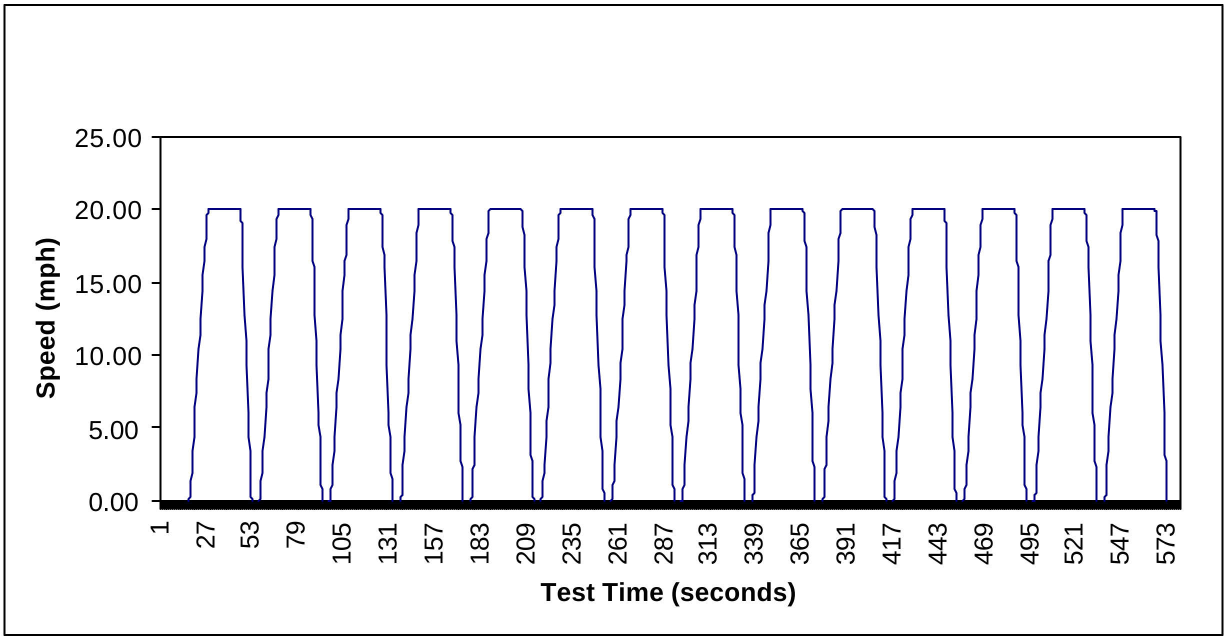
The use of standard driving schedules for heavy-duty HEV certification will also require the development of minimum certification emission standards for a given driving schedule. Presently, an engine dynamometer certification requires that emission levels in grams per brake horsepower-hour (g/bhp-hr) be met. As envisioned, emissions will be measured on a grams per mile (g/mi) basis since the buses would be tested on a chassis dynamometer, similar to car and light duty truck certification testing. Staff is collecting data on conventional heavy-duty diesel transit buses that have undergone chassis dynamometer testing. With these data, staff should be able to identify realistic certification standards for heavy-duty HEV transit buses that would also enable a direct comparison with chassis emissions test results for conventional diesel and alternative-fuel heavy-duty transit buses.

B. Current Heavy-Duty HEV Testing

ARB is currently evaluating two heavy-duty HEV buses (an Orange County Transportation Authority New Flyer and a Torrance Transit Orion) at the ARB Heavy-Duty Emissions Test Laboratory. Each of these vehicles is tested using standard heavy-duty driving schedules. Prior to the emissions test, staff met with the owner of each HEV bus, representatives from the HEV drivetrain manufacturer, and other interested parties to identify the most appropriate driving schedule for testing. Two driving schedules are usually used to ensure the full range of operating conditions are tested and recorded. These schedules are the Central Business District (CBD) and the Urban Dynamometer Driving Schedule (UDDS).

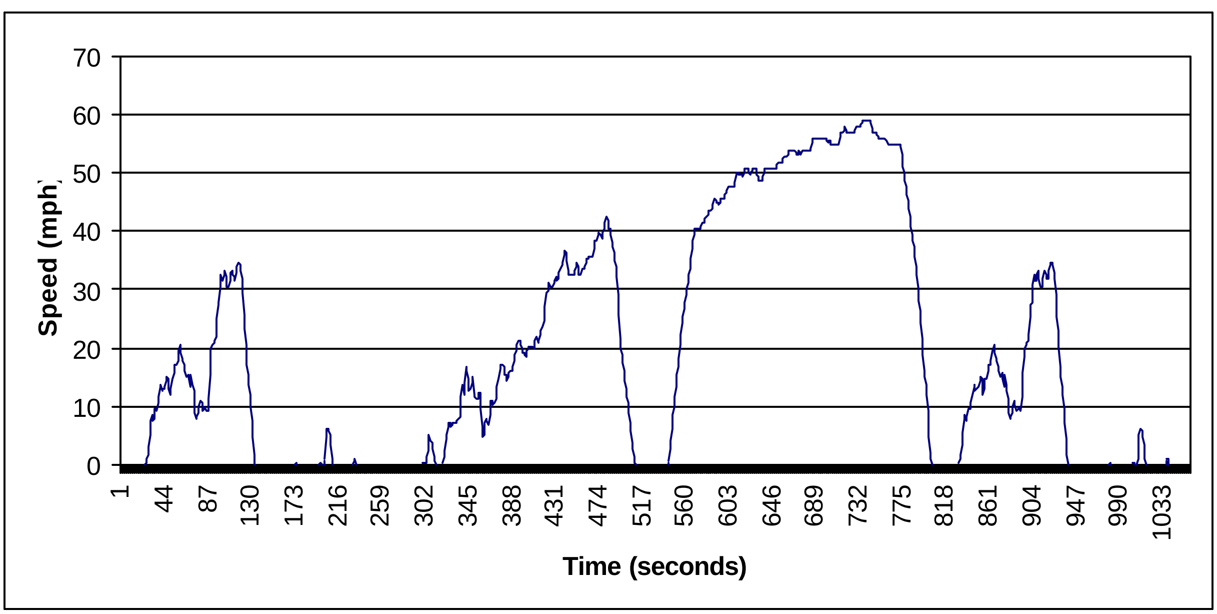
The CBD cycle (Figure 5) is a bus performance cycle that was developed by the Federal Transit Administration several years ago. In the bus procurement process, it provides assurance to transit operators that the bus will meet the relatively extreme road acceleration and braking demands of urban operation. The road speed never exceeds 20 miles/hour during the test, and the cycle is simply a repetition of hard stop and go vehicle operation as a bus might typically experience in a congested urban area. This test procedure has become the most common emissions test cycle for urban transit buses. There is a wealth of emissions data available for many types of conventional diesel and alternative-fueled buses.

FIGURE 5: Central Business District Drive Cycle



The UDDS cycle (Figure 6) is a chassis dynamometer test facsimile of the heavy-duty engine dynamometer certification cycle. This cycle was originally intended to simulate heavy-duty truck operation. Consequently, it has a broader range of road speeds than the CBD cycle, the highest speed reached being 58 miles/hour. The UDDS cycle should be considered for use in hybrid certification because many hybrid buses will be operated under higher speed highway conditions, as well as in congested urban areas.

FIGURE 6: Urban Dynamometer Driving Schedule



There are other test cycles for HEV being considered by various members of the HEV industry. Because California transit bus fleets perform a wide range of in-use driving patterns, the CBD, NYCBC, or UDDS cycles may not simulate real driving conditions for many fleets. For example, the rapid braking schedule of the CBD cycle may not allow the full benefit of regenerative braking to be realized during the emissions testing. Staff intends to work with the various hybrid industry representatives to sort out the issues with the proposed hybrid test cycles.

ARB will continue to cooperate with federal programs to ensure that California's Heavy-Duty Hybrid Bus regulations and test procedures adequately coincide with those under the U.S. EPA program. As part of the Northeast Advanced Vehicle Consortium (NAVC) Heavy-Duty Hybrid Bus Work Group, members of industry, academia, and the federal government are working to develop new heavy-duty hybrid bus test procedures. Industry members include heavy-duty truck companies, hybrid drive train developers, and bus manufacturers. Inevitably, chassis based dynamometer test procedures will likely be used to determine emission levels for hybrid vehicle certification.

Over the past two years the workgroup has successfully established draft hybrid test guidelines. In developing heavy-duty hybrid bus test procedures, the workgroup initially relied on the extensive work within the Society of Automotive Engineering [(SAE) J1711]. Although the SAE J1711 procedures were developed for light-duty hybrid vehicles, a significant portion of the procedures is applicable for heavy-duty HEVs. ARB's close working relationship with its federal counterparts within the Heavy-Duty Hybrid Bus Work Group will ensure close coordination between California and federal heavy-duty hybrid bus certification programs. Given the need by California to have heavy-duty hybrid certification procedures in place to support new rules and regulations, it may be necessary for ARB to have California interim procedures in place prior to the final SAE J1711-HD test procedures.

C. Potential Benefits of HEVs for Transit Buses

Initial testing of heavy-duty hybrid transit buses indicates that hybrid technologies have reduced emissions, improved fuel economy, and potentially lower maintenance requirements. Under a recent Northeast Advanced Vehicle Consortium (NAVC) test program, an Orion-LMCS diesel hybrid achieved a fuel economy of 2.3 mpg under the New York City Bus Cycle (Tables 5 & 6) (Bradley & Associates 2000). A comparable conventional diesel bus offered a fuel economy of 1.4 mpg. This corresponds to a fuel economy improvement of about 65 percent. Although hybrid-electric technology for heavy-duty vehicles is at an early stage of development, the potential benefits of this technology suggest that many transit bus fleet operators would seriously consider the use of hybrid technology for their particular applications, since fuel is one of their major operating costs.

Table 5: Bus Specifications

Bus Type	NOVA-Allison Hybrid	NOVA Diesel
Fleet Owner	NY City Transit Authority	NY City Transit Authority
Gross Vehicle Weight	36,900 lbs.	39,500 lbs.
Curb Weight	30,600 lbs.	28,200 lbs.
Test Weight	34,735 lbs.	32,250 lbs.
Passenger Capacity	52	52
Engine	VM Motori VM 642 (1998)	Detroit Diesel Series 50 (1999)
Fuel	CARB Diesel	Diesel
Transmission	Allison Hybrid Electric	3-Speed Automatic

Table 6: Summary of Dynamometer Test Results for Central Business Cycle and New York Bus Cycle

Bus	Test	CO (g/mi)	NOx (g/mi)	NMOC (g/mi)	PM (g/mi)	MPG
NOVA Hybrid	CBD	0.4	27.7	bdl	bdl	3.9
NOVA Diesel	CBD	3.0	30.1	0.14	0.24	3.5
NOVA Hybrid	NYBC	0.6	58.9	0.07	bdl	1.7
NOVA Diesel	NYBC	11.3	72.0	0.60	0.70	1.4
Orion-LMCS Hybrid Diesel	NYBC	5.0	40.5	1.13	0.16	2.3

***bdl: below detection limit**

To date, one diesel hybrid-electric engine, Capstone MicroTurbine, has been certified based on its turbine output and engine dynomometer testing. The diesel and LPG turbines were certified to 1.3 g/bhp-hr total HC and 1.0 g/bhp-hr NOx, while the CNG turbines were certified to 1.2 g/bhp-hr NMHC and 0.5 g/bhp-hr NOx. Thus, these engines do meet the 2004-2006 MY NOx standard of 2.5 g/bhp-hr total combined NOx and NMHC.

D. Development of California Certification Procedures for Heavy-Duty Hybrid Vehicles

Staff has determined that new test procedures are needed to accurately assess emissions from hybrid-electric buses. Staff must carefully consider the unique operation of heavy-duty hybrid drive trains and identification of appropriate driving cycles.

The J1711HD procedures, while still under development, are the basis for ARB's test development program. SAE's initial objective is to provide test procedures for the straightforward comparison of hybrid bus emissions to conventional bus emissions. J1711HD could ultimately form the basis of the heavy-duty hybrid certification procedures in California.

ARB will continue to work with hybrid bus manufacturers, hybrid drive train developers (e.g., BAE Systems and Allison), and transit bus fleet managers to further understand the operating characteristics and maintenance concerns of transit buses, both conventional and hybrid designs. Staff will work closely with key industry officials to facilitate the development of durability requirements, such as emission deterioration factors, in-use compliance measures, and onboard diagnostics requirements.

ARB staff plans to propose heavy-duty hybrid-electric vehicle test procedures for the Board's consideration and adoption by late 2002. With the adoption of these procedures, transit bus fleet operators will be able to introduce certified lower-emitting hybrid-electric buses into their active fleets, thereby reducing the emissions from buses and providing an environmental benefit to the people of California.

VI. SUMMARY AND STAFF RECOMMENDATIONS

A. Summary

The Board, through discussion at the February 24, 2000, public hearing and Resolution 00-2 (February 24, 2000), directed staff to provide regular updates on the progress of implementation of the regulation. Specifically, directives to staff were (1) to report back regularly on transit agency progress in implementing regulations; (2) report back to the Board on implementation of emission reduction strategies as an alternative to compliance with the 2004 standards and to analyze the first exemption application and present its recommendation before the Board as part of the first update (3) , to report on the status of advanced aftertreatment systems; and (4) to report on progress on the development of hybrid-electric bus test procedures.

Each transit agency to which the rule applied was required to select a fuel path and submit its selection by January 31, 2001. Seventy transit agencies are subject to the regulation. Of these transit agencies, 61 percent chose to follow the diesel path while 39 percent chose to follow the alternative-fuel path. As of January 31, 2001, transit agencies reported that they operate 6679 diesel buses and 1866 alternative-fuel buses. By October 1, 2002, transit agencies report they will operate 6158 diesel buses, a decrease of 8 percent, and 2754 alternative-fuel buses, an increase of 48 percent.

Transit agencies were required to submit their NOx fleet averages, based on engine certification values, as of January 1, 2001. If the NOx fleet average was higher than 4.8 grams per brake horsepower-hour (g/bhp-hr), transit agencies were required to submit a report detailing actions planned to achieve that average by October 1, 2002. As of August 1, 2001, 68 of the 70 transit agencies subject to this rule had submitted both the 2001 and 2002 NOx fleet averages. Eighty-two percent of the transit agencies either presently comply with the 4.8 g/bhp-hr NOx fleet average or will by October 1, 2002. Transit agencies will be retiring, repowering or purchasing alternative fuel buses to lower their fleet emission averages. Eleven transit agencies submitted data that, according to staff’s analysis, indicates they will continue to exceed the 4.8 g/bhp-hr fleet average; staff has contacted these transit agencies and will work with them to move them into compliance.

The engine standards in title 13, CCR, section 1956.1 prohibit transit agencies from purchasing transit bus engines during model years 2004 through 2006 that exceed a NOx emission standard of 0.5 g/bhp-hr. The regulation includes an alternative strategy that the transit agencies can follow if transit bus engines meeting this standard are not available, as engine manufacturers have indicated is possible. The strategy allows transit agencies the option to apply for an exemption by June 30, 2001, from purchasing engines that meet the 2004-2006 MY engine emission standards. Transit agencies that are approved for the exemption may purchase 2004-2006 MY diesel engines with certified NOx emissions of 2.5 g/bhp-hr combined NOx + NMHC. The exemption is the only mechanism allowed by the law for transit agencies to purchase non-complying diesel engines during those three years.

Among the 15 exemption applications received by the June 30 deadline, Santa Clara Valley Transit Authority was the only transit agency, as of August 15, 2001, that submitted a completed plan that demonstrates greater NOx emission benefits through 2015. Staff's analysis of the plan shows that the plan meets the requirement of the regulation, and thus provides a good framework that can be followed by other transit agencies. All of the other transit agencies that submitted an application for exemption requested additional time and assistance in preparing plans, or needed to submit additional information. In addition, between June 30 and August 15, 2001, staff has receive one letter and several verbal requests by transit agencies that would like to submit late exemption applications.

None of the transit agencies that applied for exemptions as of June 30, 2001, indicated that they were demonstrating or have contracted to demonstrate advanced NOx aftertreatment technology. This is an important requirement of the exemption regulation and is necessary to ensure viability of the technology for meeting the 2007 engine exhaust standards. However, the national NOx standards which were slated for implementation in 2007, when the transit bus regulation was adopted, have now been finalized for 2010. This change translates into a delay of early demonstration programs, so NOx emission controls are not yet available to transit agencies.

Transit agencies are required to reduce particulate matter emissions through retrofitting their bus engines with advanced aftertreatment technology that reduces particulate matter exhaust emissions by a minimum of 85 percent. Staff has established a program to verify these aftertreatment devices, and as of August 2, 2001, two devices applicable to some later model engines have been verified. Currently there are no retrofit devices verified for engines older than 1995 MY and no devices are verified for any two-stroke engines. The transit bus rule requires transit agencies retrofit 100 percent of their pre-1991 MY diesel engines, and differing percentages of their 1991 to 1995 MY diesel engines, depending on their fuel path, by January 1, 2003. The regulation provides for a one year delay in the event that retrofit devices are not available within six months of the required implementation date. Staff therefore will update the Board by July 2002 on the availability of particulate matter retrofit devices for older engines.

Staff has provided an update on the status of NOx aftertreatment technology in this report. Controlling NOx emissions from diesel engines is inherently difficult because the oxygen-rich exhaust environment makes reduction, the removal on an oxygen molecule, difficult to achieve. NOx absorbers have shown greater than 80 percent reduction potential in development programs, and are considered one of the most promising technologies for NOx reduction. Selective catalytic reduction has been in use in stationary sources for many years, but to date its application in mobile sources is limited and still under development. Manufacturers are focusing research and development efforts on achieving significant (i.e., 90 percent) emission reductions in the 2007 to 2010 time frame. However, the national NOx standards which were slated for implementation in 2007, when the transit bus regulation was adopted, have now been finalized for 2010. This change translates into a delay of early demonstration programs, so NOx emission controls are not yet available to transit agencies.

Staff was also instructed to develop a test procedure for the evaluation of hybrid-electric bus emissions. This issue requires more time to resolve. ARB is actively participating in a government-industry working group and is testing hybrid-electric bus emissions to develop a test procedure and certification standards. Staff anticipates updating the Board with a test procedure for certification of diesel hybrid-electric bus systems in late 2002.

B. Staff Recommendations

Staff has analyzed the implementation issues and exemption applications for the alternative NOx reduction strategy. Based on these analyses and the delay in the full compliance date for the national NOx standards, staff makes the following recommendations to the Board:

- Staff recommends that the Board direct the Executive Officer to allow transit agencies that applied for an exemption and submitted a plan demonstrating greater NOx benefits through 2015 additional time to demonstrate advanced NOx aftertreatment technology. The schedule staff recommends is as follows: transit agencies must commit resources to a demonstration project as of March 31, 2002, and advanced NOx aftertreatment demonstrations must be in progress as of March 31, 2003.

- Staff further recommends the Board allow each transit agency the option of performing the demonstration individually or jointly. If the transit agencies elect a joint project, then the demonstration must include at least three buses and demonstrate NOx aftertreatment technology that will offer commercial potential (i.e., lower NOx emissions by 70-90 percent). Transit agencies that elect individual demonstrations shall include at least one bus.

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